
***In vitro* comparison of root-canal measurements with conventional and digital radiology**

A. Lozano, L. Forner, C. Llana

Endodontic, Dental Pathology and Therapeutics Unit, Department of Stomatology, Faculty of Medicine and Dentistry, University of Valencia, Spain

Abstract

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Aim The present study compared the efficacy of digital and conventional radiology for root-canal length measurement.

Methodology Seventy extracted teeth with preserved roots were used. Root-canal length measurements were completed with K-Flexofiles (numbers 08, 10 and 15) with conventional and digital radiography using two systems (radiovisiography and photostimulate storage phosphor). All films and sensors were exposed at projections of 0° and 20° to the mesial. The images obtained were evaluated with and without magnification, and analysed using the Cohen's kappa test. The accuracy of the three systems to determine

the root-canal length were evaluated by measuring the distance from the tip of the file to the apex.

Results Most of the values corresponding with the apex occurred with conventional radiology. The digital systems yielded negative values that improved with a size 15 file. The agreement between the two digital systems was the best with size 15 file using 0° projection (66.7%).

Conclusions Conventional radiology remains the technique of choice in determining the root-canal length; the digital techniques yielded good results for size 15 file.

Keywords: endodontics, photostimulate storage phosphor system, radiology, radiovisiography, root-canal length.

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Introduction

Knowledge of the root-canal systems is essential for diagnosis and treatment. As in other fields of science, the development of diagnostic imaging techniques in dentistry has been of fundamental importance. The application of such techniques in endodontics allows the definition of root and canal morphology, and particularly the determination of endodontic working length and final verification of the outcome of root-canal treatment (Versteeg *et al.* 1997).

Technological advances have led to the introduction of digital radiology (DR), with many potential benefits in

endodontic practice (Mouyen *et al.* 1989, Shearer *et al.* 1990, Horner *et al.* 1990, Shearer *et al.* 1991, Furkart *et al.* 1992, Soh *et al.* 1993). The first commercial integrated digital imaging system was radiovisiography (RVG; Trophy Radiologie, Vincennes, France), involving the use of an intraoral, sensor instead of conventional X-ray film (Mouyen *et al.* 1989, Benz & Mouyen 1989). The RVG allowed a substantial reduction in the duration of endodontic procedures, because it effectively eliminated the film-processing time. In the same way, the zoom function had the potential to improve the diagnostic performance by magnifying areas such as the apical zone (Duret *et al.* 1988).

By measuring the intra-root-canal length, it was shown that no statistically significant differences exist between the images provided by a rigid sensor such as RVG and the conventional film (Shearer *et al.* 1990). The digital radiological systems have been compared with

Correspondence: Dr Adrián Lozano, Endodontic, Dental Pathology and Therapeutics Unit, Department of Stomatology, Faculty of Medicine and Dentistry, Gasco Oliag, I. 46010, Valencia, Spain (Tel.: + 34609308202, E-mail: endoala@wanadoo.es).

conventional images obtained using E-speed film for the diagnosis of experimentally induced periapical lesions (Kullendorf *et al.* 1996). In this context, the direct digital-image quality was comparable to that produced by the conventional film (E-speed), although modification of the basic features of a digitized image (i.e. brightness and contrast) has little advantage when compared with the original image, provided the latter is of high quality. This has also been demonstrated (Kullendorf *et al.* 1996) with the Visualix/Vixa system (Gendex Dental Systems, Milan, Italy).

One variant of such digital radiological technology is based on the reading of a reusable plate previously exposed to X-rays from a conventional generator (Kashima *et al.* 1985, Seki & Okano 1993, Kashima *et al.* 1994). This type of DR is known as the photostimulate storage phosphor (PSP) system (Digora, Soredex, Orion Corporation, Helsinki, Finland). Most of the energy from the radiation of the conventional generator is maintained in the surface of the plate; a scanner is then used to read this energy and to convert it into a digital signal that is recognized by the computer and presented on screen.

One of the most significant characteristics of digital radiological systems is the fact that their sensors make it possible to reduce the radiation dose by 60% (Seki & Okano 1993, Kashima *et al.* 1994, Sanderink *et al.* 1994). Other recently developed sensors allow even lower exposure levels, although possibly, at the expense of the image quality. Nevertheless, in a study of the endodontic diagnostic utility of the sensors of the Sidexis (Siemens, Erlangen, Germany) and Digora (Soredex, Orion Corporation) systems, involving radiation dose reductions of up to 95%, both systems were able to determine root-canal length in premolars using size 20 files (Velders *et al.* 1996).

Observer accuracy in determining the working length has been studied *in vitro* contrasting the conventional radiography (E-speed) and RVG. No differences were observed between conventional film images and the printed RVG image, although the former were significantly more precise than the computed image on the high-resolution screen (Hedrick *et al.* 1994). Some authors reported a limitation in the diagnostic capacity of the digital technique and defined a minimum calibre that could be visualized without difficulty (Sanderink *et al.* 1994) in relation to a size 15 file. Other authors suggested that conventional radiography cannot be replaced by digital techniques (Lavelle & Wu 1995). When comparing RVG and conventional radiography (D- and E-speed) in detecting small intracanal instruments *in vitro*, it was demonstrated that 2 × magnification for visualizing

the size 08 and 10 file tips was more accurate with conventional radiography than with RVG (Ellingsen *et al.* 1995). Similar results were obtained contrasting the RVG and conventional film images when performing root-canal measurements *in vitro* with a size 15 file (Ong & Pitt Ford 1995). In a recent study involving cone-vertical angles of up to 30° for estimating the working length with the conventional (D-speed) and digital radiography, no significant differences were observed in the results afforded by both techniques, with the exception of image shortening at an angle of 30° when using digital radiology (Almenar *et al.* 1997).

When using the Digora system with different exposure times, it was concluded that endodontic measurements could be obtained at considerably lower exposures than those required with the conventional film systems (Borg & Gröndahl 1996). A comparison of the Digora system and conventional film images (E-speed) revealed no significant differences in the estimation of working length, although the former technique was more accurate in visualizing file tips, particularly when small (Cederberg *et al.* 1998).

The present study compared the diagnostic efficacy of two digital radiological systems in performing root-canal measurements and correlated them to conventional film radiography whilst assessing the influence of different projection angles and the use of magnification.

Materials and methods

A total of 70 teeth extracted for orthodontic and periodontal reasons and obtained from different sources with or without caries were studied. The teeth were kept in 37% aqueous formaldehyde solution with 10% methanol. There were five teeth corresponding to each tooth type from both jaws: central and lateral incisors, canines, first and second premolars, and first and second molars. A digital CCX 70 kVp and 8 mA X-ray generator (Trophy Radiologie, Vincennes, France) with DF58 radiographic film (Eastman Kodak Company, Rochester, NY, USA) was used. Two digital radiological systems were also selected. (a) Radiovisiography (RVG 4, Trophy), consisting of a computer, monitor and software (Trophy 97) under MS Windows 95 to visualize, modify and store the image obtained, and a sensor (HDS, with a resolution of 12 pixels mm⁻¹). The corresponding image appeared on screen in manual format and could be modified in terms of contrast brightness and magnification. (b) PSP system (Digora, Soredex, Orion Corporation, Helsinki, Finland), consisting of a computer, monitor and software

(Digora 1.51) under MS Windows 95, with a scanner and reusable imaging plate. The standard plate was used with a resolution of 6 pixels mm^{-1} . The corresponding image appeared on screen and could be modified in terms of contrast, brightness and magnification.

An apparatus with tooth-positioning and angle-measurement functions was used that was similar to a device assessed previously (Forsberg 1987). The teeth were positioned in a geometrically standardized support incorporating a horizontal goniometer. As a result, it was not necessary to rotate the X-ray tube; rather, the tooth-supporting post was turned, and the appropriate horizontal grading of the X-ray beam with respect to each tooth was selected directly.

An automatic Periomat developer (Dürr Dental GmbH & Co., Bietigheim-Bissingen, Germany) was used to ensure uniform development of the conventional films.

Access cavity preparation was carried out using a round diamond bur 801/014 (Komet, Lemgo, Germany) and the canals were located with a probe. K-Flexofile Col-orinox instruments (sizes 08, 10 and 15; Dentsply Maillefer, Ballaigues, Switzerland) were used. The root-canal lengths were assessed by placing each file size inside the canal; the working length was recorded when the tip of the file was seen at the apical foramen. Conventional radiography, RVG and PSP systems were used in turn with the teeth positioned on the supporting post. In order to ensure reproducible and centred tooth-positioning, marks were made in the centre of the buccal and proximal surfaces of the teeth, coinciding with marks on the supporting post. The X-ray cone was in turn placed on a support to allow exact parallel alignment with the dental support both horizontally and vertically. In order to keep the film perpendicular to the beam at all times, an XCP radiographic support (Rinn Corporation, Elgin, IL, USA) was used fixed to the X-ray tube. The PSP system plate was positioned in the same way, whilst the RVG sensor was fixed with elastic bands. Two projections were used for each tooth (0° and 20° mesial). The horizontal angle was modified by turning the goniometer and hence also the supporting post; the vertical angle was directly selected from the X-ray tube (90°). In all cases a distance of 5 cm was established between the X-ray source and the specimen, with 1 cm between the latter and the film or sensor.

The distance from the file tip to the radiographic apex was measured, recording the values as positive, zero or negative (i.e. beyond the apex, at the apex, and short of the apex). In the case of the conventional film images the measurements were made directly on the film when assessed on a X-ray viewer and under $6\times$ magnification

using a Diastar 200 slide viewer (Osram, Austria). In the case of the digital systems, measurement was carried out by calibrating the apparatus for each projection by placing a wire of known length alongside the specimen support post. The RVG measurements were made of the original image and also of the 100% magnified image. The same approach was used with the Digora system by using a maximum magnification of 200%. All the measurements were made by a trained observer.

The percentage of concordance and the Cohen's kappa test of the grading system (through, at, short of apex) were used to determine agreement between two different techniques, eliminating the coincidences attributable to chance. Intra-observer error was assessed by re-reading a random sample of 10% of the teeth. The percentage of concordance between the two group of measurements was evaluated in order to determine the reproducibility of the results.

Results

The measurement of the distance of the file tip to the radiographic apex was considered optimum when the resulting value was zero (in this case, the foramen was at the radiographic apex). Negative values meant that the tip of the file was short of the radiographic apex. Based on the three techniques examined in the present study, with the different angles and magnifications involved and using three different file sizes (08, 10 and 15), the mean values of the measurements of all the teeth and for each file size were computed (Tables 1, 2 and 3). **1 Size 08 file, 0° angle:** most of the values corresponding with the apex occurred with the conventional film ($n = 46$; 65.7%); the RVG and Digora systems yielded more negative mean values ($n = 27$; 38.6% and $n = 47$; 68.1%, respectively) (Table 4).

Table 1 Mean distance of size 08 file tip in relation to radiographic apex of tooth

	Mean	SD	Minimum	Maximum
Rad 0°	0.00	0.08	-0.30	0.20
Digora 0°	-0.14	0.17	-0.50	0.30
RVG 0°	-0.05	0.10	-0.30	0.10
Rad 0° magnif.	0.01	0.11	-0.50	0.20
Digora 0° magnif.	-0.12	0.16	-0.50	0.30
RVG 0° magnif.	-0.04	0.09	-0.30	0.10
Rad 20° magnif.	0.01	0.08	-0.30	0.20
Digora 20° magnif.	-0.12	0.15	-0.50	0.20
RVG 20° magnif.	-0.02	0.06	-0.20	0.10
Rad 20°	0.00	0.08	-0.30	0.20
Digora 20°	-0.13	0.16	-0.60	0.20
RVG 20°	-0.04	0.08	-0.30	0.10

Table 2 Mean distance of size 10 file tip in relation to radiographic apex of tooth

	Mean	SD	Minimum	Maximum
Rad 0°	-0.01	0.07	-0.30	0.20
Digora 0°	-0.08	0.14	-0.40	0.20
RVG 0°	-0.02	0.07	-0.30	0.10
Rad 0° magnif.	0.00	0.10	-0.60	0.30
Digora 0° magnif.	-0.06	0.14	-0.40	0.40
RVG 0° magnif.	-0.02	0.08	-0.30	0.10
Rad 20° magnif.	0.00	0.09	-0.40	0.30
Digora 20° magnif.	-0.08	0.14	-0.50	0.20
RVG 20° magnif.	-0.02	0.06	-0.30	0.10
Rad 20°	0.00	0.07	-0.20	0.30
Digora 20°	-0.09	0.14	-0.50	0.20
RVG 20°	-0.02	0.06	-0.30	0.10

Table 3 Mean distance of size 15 file tip in relation to radiographic apex of tooth

	Mean	SD	Minimum	Maximum
Rad 0°	-0.01	0.06	-0.20	0.20
Digora 0°	-0.05	0.13	-0.30	0.20
RVG 0°	-0.03	0.08	-0.30	0.10
Rad 0° magnif.	0.00	0.08	-0.40	0.30
Digora 0° magnif.	-0.05	0.13	-0.30	0.20
RVG 0° magnif.	-0.02	0.07	-0.30	0.10
Rad 20° magnif.	0.00	0.06	-0.30	0.20
Digora 20° magnif.	-0.07	0.12	-0.60	0.13
RVG 20° magnif.	-0.02	0.07	-0.30	0.10
Rad 20°	0.00	0.05	-0.10	0.20
Digora 20°	-0.07	0.13	-0.60	0.13
RVG 20°	-0.02	0.07	-0.30	0.10

2 Size 08 file, 0° angle with magnification: with conventional radiography positive mean values were obtained (0.01 mm) whilst the other techniques gave negative values. Radiology gave more positive values ($n = 28$; 40%); Digora continued with negative values ($n = 46$; 66.7%) but RVG showed zero values in over 51.4% ($n = 36$) (Table 4).

3 Size 08 file, 20° angle with magnification: the results were similar to those of the previous group (Table 4).

4 Size 08 file, 20° angle: the Digora system resulted in most negative measurements ($n = 45$; 65.2%). The RVG also showed negative values ($n = 26$; 37.1%) whilst the conventional film gave optimum measurements ($n = 47$; 67.1%) (Table 4).

Radiography at 0° and 20° in the absence of magnification gave zero results in over 60% of cases. It should be noted that the positive values only appeared when magnification was used. In comparison, RVG yielded the least positive measurements with a similar incidence of

Table 4 Distance of size 08 file tip in relation to apex

		N	Percentage
Rad 0°	Negative	11	15.7
	Zero	46	65.7
	Positive	13	18.6
Digora 0°	Negative	47	68.1
	Zero	14	20.3
	Positive	8	11.6
RVG 0°	Negative	27	38.6
	Zero	37	52.9
	Positive	6	8.6
Rad 0° magnif.	Negative	14	20.0
	Zero	28	20.0
	Positive	28	40.0
Digora 0° magnif.	Negative	46	66.7
	Zero	15	21.7
	Positive	8	11.6
RVG 0° magnif.	Negative	26	37.1
	Zero	36	51.4
	Positive	8	11.4
Rad 20° magnif.	Negative	14	20.0
	Zero	31	44.3
	Positive	25	35.3
Digora 20° magnif.	Negative	44	63.8
	Zero	44	29.0
	Positive	5	7.2
RVG 20° magnif.	Negative	25	35.7
	Zero	42	60.0
	Positive	3	4.3
Rad 20°	Negative	11	15.7
	Zero	47	67.1
	Positive	12	17.1
Digora 20°	Negative	45	65.2
	Zero	19	27.5
	Positive	5	7.2
RVG 20°	Negative	26	37.1
	Zero	41	58.6
	Positive	3	4.3

zero values. However, RVG had negative measurements in approximately 40% of cases (Table 1).

5 Size 10 file, 0° angle: all the systems gave negative values although conventional film had fewer negative values ($n = 11$; 15.7%) than the others (Table 5).

6 Size 10 file, 0° angle with magnification: the best results were obtained with conventional film ($n = 38$; 54%) and with RVG ($n = 42$; 60%); Digora recorded values that were less negative than with the size 08 file ($n = 42$; 60.9%) (Table 5).

7 Size 10 file, 20° angle with magnification: the conventional film and RVG were similar to those of the previous

Table 5 Distance of size 10 file tip in relation to apex

		N	Percentage
Rad 0°	Negative	11	15.7
	Zero	50	71.4
	Positive	9	12.9
Digora 0°	Negative	43	62.3
	Zero	15	21.7
	Positive	11	15.9
RVG 0°	Negative	21	30.0
	Zero	42	60.0
	Positive	7	10.0
Rad 0° magnif.	Negative	15	21.4
	Zero	38	54.3
	Positive	17	24.3
Digora 0° magnif.	Negative	42	60.9
	Zero	15	21.7
	Positive	12	17.4
RVG 0° magnif.	Negative	20	28.6
	Zero	42	60.0
	Positive	8	11.4
Rad 20° magnif.	Negative	13	18.6
	Zero	42	60.0
	Positive	15	21.4
Digora 20° magnif.	Negative	39	56.5
	Zero	18	26.1
	Positive	12	17.4
RVG 20° magnif.	Negative	19	27.1
	Zero	46	65.7
	Positive	5	7.1
Rad 20°	Negative	12	17.1
	Zero	49	70.0
	Positive	9	12.9
Digora 20°	Negative	39	56.5
	Zero	18	26.1
	Positive	12	17.4
RVG 20°	Negative	21	30.0
	Zero	43	61.4
	Positive	6	8.6

Table 6 Distance of size 15 file tip in relation to apex

		N	Percentage
Rad 0°	Negative	10	14.3
	Zero	55	78.6
	Positive	5	7.1
Digora 0°	Negative	29	42.0
	Zero	28	40.6
	Positive	12	17.4
RVG 0°	Negative	17	24.3
	Zero	47	67.1
	Positive	6	8.6
Rad 0° magnif.	Negative	10	14.3
	Zero	52	74.3
	Positive	8	11.4
Digora 0° magnif.	Negative	29	42.0
	Zero	28	40.6
	Positive	12	17.4
RVG 0° magnif.	Negative	17	24.3
	Zero	47	67.1
	Positive	6	8.6
Rad 20° magnif.	Negative	11	15.7
	Zero	52	74.3
	Positive	7	10.0
Digora 20° magnif.	Negative	37	53.6
	Zero	22	31.9
	Positive	10	14.5
RVG 20° magnif.	Negative	15	21.4
	Zero	51	72.9
	Positive	4	5.7
Rad 20°	Negative	9	12.9
	Zero	55	78.6
	Positive	6	8.6
Digora 20°	Negative	37	53.6
	Zero	22	31.9
	Positive	10	14.5
RVG 20°	Negative	15	21.4
	Zero	51	72.9
	Positive	4	5.7

group, but Digora presented more negative values ($n = 39$; 56.5%) (Table 5).

8 Size 10 file, 20° angle: the conventional film continued to offer the most accurate results ($n = 49$; 70%), the RVG and Digora were similar to the previous group (Table 5).

No differences for a given technique are seen according to the angles or magnifications used. The RVG yielded mean values very close to 0 (−0.02 mm) (Table 2).

9 Size 15 file, 0° angle: the conventional film gave more positive values ($n = 55$; 78.6%) as well as RVG ($n = 47$;

67.1%). The Digora recorded less negative values ($n = 29$; 42%) (Table 6).

10 Size 15 file, 0° angle with magnification: conventional radiography continues to offer the most accurate results ($n = 52$; 74.3%), whilst the Digora system improved somewhat in comparison with the measurements obtained with size 08 and 10 files ($n = 28$; 40.6%); RVG performance remained as before (Table 6).

11 Size 15 file, 20° angle with magnification: radiography obtained the best results ($n = 52$; 74.3%). The RVG gave more zero values ($n = 51$; 72.9%) and Digora was similar to the previous group (Table 6).

Table 7 Kappa index and percentage of concordance corresponding to size 08, 10 and 15 files with the different techniques studied

	Kappa (concordance%) file 08	Kappa (concordance%) file 10	Kappa (concordance%) file 15
Rad 0° and Digora 0°	0.056 (30.4%)	0.101 (34.7%)	0.143 (47.8%)
Rad 0° magnif. and Digora 0° magnif.	0.09 (33.3%)	0.038 (31.8%)	0.04 (40.5%)
Rad 20° and Digora 20°	0.089 (36.2%)	0.127 (39.1%)	0.089 (39.1%)
Rad 20° magnif. and Digora 20° magnif.	0.112 (36.2%)	0.049 (33.3%)	0.04 (36.1%)
Rad 0° and RVG 0°	0.231 (55.8%)	0.218 (60%)	0.106 (61.4%)
Rad 0° magnif. and RVG 0° magnif.	0.131 (41.5%)	0.073 (45.8%)	−0.101 (54.4%)
Rad 20° and RVG 20°	0.129 (52.9%)	0.296 (64.3%)	−0.012 (60%)
Rad 20° magnif. and RVG 20° magnif.	0.051 (38.6%)	0.101 (51.4%)	−0.022 (57.2%)
Digora 0° and RVG 0°	0.319 (57.9%)	0.39 (59.3%)	0.454 (66.7%)
Digora 0° magnif. and RVG 0° magnif.	0.351 (59.4%)	0.377 (57.9%)	0.454 (66.7%)
Digora 20° and RVG 20°	0.387 (63.7%)	0.446 (63.7%)	0.257 (52.2%)
Digora 20° magnif. and RVG 20° magnif.	0.39 (63.8%)	0.409 (60.8%)	0.257 (52.2%)

12 Size 15 file, 20° angle: the results were similar to those of the 15 file, 20° with magnification (Table 6).

All the systems yielded negative mean values in absence of angulation and magnification. Conventional radiography gave the most accurate mean values when angulation and magnification were used; however, RVG was close to 0 (Table 3).

The agreement amongst the different techniques is reflected in Table 7, where both the percentage of concordance and Cohen's kappa test values were low for all the situations analyzed. The best results for percentage of concordance and the Cohen's kappa test were obtained when digital systems were compared; neither angulation nor magnification had any influence.

Discussion

A number of fundamental issues need to be resolved before digital radiology can be fully incorporated into clinical practice (Van Der Stelt 1995). The radiological diagnostic techniques used in the present study were chosen to reflect current interest in comparing the performances of digital and conventional radiology and assessing their applicability to root-canal measurements (Shearer *et al.* 1990, Shearer *et al.* 1991, Hedrick *et al.* 1994, Ellingsen *et al.* 1995, Ong & Pitt Ford 1995).

When obtaining radiographic images of any kind, the purpose of the radiographic sensing component (either digital or conventional) is to capture X-ray photon density emerging from the target tissues. This is, in turn, determined by the tissues involved and the radiation source used. In this sense, the image will be more precise if a point-source is employed. Another important consideration in this context is the size of the focal point of

the X-ray generator, because it exerts a decisive influence upon the capacity of the system to discriminate between two points in close proximity to each other (Sprawls 1977). In practice, however, the X-ray generators emit from an extensive zone rather than from a point-source; consequently, the X-ray images obtained suffer a degree of distortion and loss of detail. As the photon dispersion pattern cannot be improved upon by the sensor, image quality and precision remains limited in both conventional and digital radiographic systems.

In the case of the PSP (Digora) technique, endodontic measurements were found to be possible at exposure levels considerably lower than those required by the conventional film techniques (Borg & Gröndahl 1996). In this context, although the exposure time may be shortened, the images do not lose quality as a result (Hayakawa *et al.* 1998). On comparing the Digora system with the conventional radiography for determining the root-canal dimensions, no significant differences were observed, although the file-tip visualization was, nevertheless more exact with PSP system, particularly when using small size files (Cederberg *et al.* 1998).

However, it is possible to improve precision in the capture of the incident X-ray photons by reducing the size of the corresponding sensor units. In the case of conventional X-ray systems, this size basically corresponds to film grain size. The current tendency is to use increasingly faster films in order to limit patient exposure; however, faster films are associated with the larger grain sizes, which result in poorer image detail; so, as our study was carried out *in vitro*, we decided to use D-speed film (Ellingsen *et al.* 1995).

The sensor unit used in digital radiological systems is the pixel. Consequently, the image quality increases with the number of pixels per unit surface. This increase in

detail can be achieved by either reducing pixel size or increasing the surface of the sensor. In this sense, RVG has a smaller pixel size than the Digora system. In the present study, a single X-ray source was used with controlled exposure time, focal distance and position. The characteristics of the conventional film used, the RVG sensor and the Digora imaging plate were also kept constant throughout the study.

It is important to mention the exposure times used to obtain the digital images (Ellingsen *et al.* 1995), because, if the same times are applied to all extracted teeth equally, some regions in the digital images may disappear upon adjusting brightness and contrast. A parallel-beam technique with two angles (0° and 20° mesial) was used in the horizontal plane in order to extrapolate the situation to *in vivo* practice, differentiating certain structures (i.e. distinguishing roots) but without creating excessive superpositioning or distortion.

Radiographic visualization is influenced by a number of physical and technical factors. In order to avoid one of the main sources of error in the production of radiographic images, an automatic developer was used to secure similar conditions for all the radiographic films used. The conventional X-ray viewing was made in the most uniform and simple way possible. Magnification was also used in an attempt to eliminate variables capable of altering image visualization (Ellingsen *et al.* 1995, Ong & Pitt Ford 1995). Although these authors used 2× and 4× magnifications, 6× magnification was used in the present study, because it improved visualization of the images.

The digital techniques make it possible to modify and analyse images in an attempt to improve the diagnostic capacity of these systems. Although such technical possibilities may seem obvious, a number of experimental studies have been made to more precisely define their true of feet (Kullendorf *et al.* 1996). Magnification of the original image does significantly increase diagnostic accuracy (Svanaes *et al.* 1996). On the other hand, if the observer has a certain experience with these techniques, imaging exerts no influence upon diagnostic accuracy (Powell-Cullingford & Pitt Ford 1993).

The file sizes used in our study were similar to those employed previously (Cox *et al.* 1991, Powell-Cullingford & Pitt Ford 1993). On comparing the reliability of RVG with conventional radiography in evaluating the locations of size 08 and 10 file tips with respect to the radiographic apex, conventional X-ray (D-speed) were clearly superior (Ellingsen *et al.* 1995). However, when using the size 15 files, similar results were obtained with both techniques (Sanderink *et al.* 1994).

The magnification of digital images provides a better image, although, this does not mean that more details are visible than in the original image. In the present study, we used no digital image modifications other than changes in the brightness and contrast, and magnification, because no advantage would be afforded by doing so (Leddy *et al.* 1994). On the other hand, on the screen images obtained with both digital techniques were used, as they offered better quality than the paper-printed images (Griffiths *et al.* 1992).

Observation of the canal-measurement images with the two digital systems revealed difficulties in precisely locating the tip of the smallest size file, although the performance improved with the increasing file size. It was also seen that this problem could be solved by magnifying the images, because the zoom function improves visualization. On the other hand, when the images were examined by several observers, with and without magnification, greater discrepancy existed amongst them than when the comparisons were made by the same observers with different types of images and techniques (Antrim 1983).

When comparing RVG and Regam digital radiographic images with conventional E-speed images in the determination of root-canal length, no significant differences were recorded between the images obtained via direct digital thermal printout and conventional X-rays (Hedrick *et al.* 1994). On contrasting conventional radiography with RVG, the latter has been seen to offer canal measurements of a quality similar to those afforded by conventional film (Shearer *et al.* 1990, Ellingsen *et al.* 1995).

Imaging with either the conventional or digital techniques was based on the reproducible and precise positioning of each tooth, thus allowing the comparison of images of the same tooth without varying the projection geometry, or doing so in a pre-established manner.

For all three file sizes used, the conventional film was seen to yield results close to 0. Similar findings were reported in another study involving size 10 files (Griffiths *et al.* 1992). However, as the file size was increased, the negative values of the Digora system were seen to decrease gradually in greater proportion than in the case of the RVG values. Likewise, all three techniques were seen to produce few measurements in excess of the mean value (Versteeg *et al.* 1997). Positive measurements with conventional radiography only occurred when magnification was used, at 0° and 20°. This could be owing to the problems in identifying the foramen with 6× magnification. The positive measurements were ones 0.01 mm in magnitude which is of no clinical relevance.

Thus, it can be confirmed that conventional radiography with any file size and regardless of the projection angle or magnification involved, offered the most accurate results. The RVG with file sizes 10 and 15 also yielded good performance, and could replace conventional film for obtaining root-canal dimensions (Shearer *et al.* 1991). In turn, the reliability of Digora in obtaining working-length measurements was similar to that of conventional film (Borg & Gröndahl 1996).

On the other hand, the three techniques showed considerable discrepancy in terms of the actual measurements obtained. However, this does not contradict the above because it referred to mean values. As an example, conventional film and RVG both gave values close to 0; however, there is little to determine that when one technique normally measures in excess, the other must also be expected to do so, or *vice versa*.

One study reported that in 82% of cases the file tip coincided with the radiographic apex, and that magnification did not influence the conventional radiographic technique (Olson *et al.* 1991).

For file sizes of 10 or smaller, digital radiography does not afford sufficient diagnostic accuracy for determining working length. In contrast, for file sizes 15 or larger, the technique approaches the performance of conventional film (Sanderink *et al.* 1994). A number of authors have reported no significant differences between RVG and conventional radiography (Leddy *et al.* 1994) in performing root-canal measurements with size 10 files, or between the Digora system and conventional film (Cederberg *et al.* 1998).

Conclusions

Conventional radiography with any size of file and regardless of the angle or magnification was the most precise imaging diagnostic technique for determining root-canal length amongst the systems examined in the present study. For file sizes larger than 15, the performance of the digital systems was similar to that of conventional radiography in terms of their capacity to diagnose working length, with no influence being exerted by the angle or magnification involved. The differences observed between the DR and conventional systems have no clinical relevance.

References

- Almenar A, Forner L, Ubet V, Miñana R (1997) Evaluation of digital radiography to estimate working length. *Journal of Endodontics* **23**, 363–5.

- Antrim DD (1983) Reading the radiograph: a comparison of viewing techniques. *Journal of Endodontics* **9**, 502–5.
- Benz C, Mouyen F (1989) Radiovisiographie. Ein System zur filmlosen Anfertigung intraoraler Zahnröntgenaufnahmen. *Deutsche Zahnärztliche Zeitschrift* **44**, 177–9.
- Borg E, Gröndahl HG (1996) Endodontic measurements in digital radiographs acquired by a photostimulable storage phosphor system. *Endodontics and Dental Traumatology* **12**, 20–4.
- Cederberg RA, Tidwell E, Frederiksen NL, Benson BW (1998) Comparison of storage phosphor digital imaging and radiographic film. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **85**, 325–8.
- Cox VS, Brown CE, Bricker SL, Newton CW (1991) Radiographic interpretation of endodontic file length. *Oral Surgery, Oral Medicine and Oral Pathology* **72**, 340–4.
- Duret F, Clunet B, Duret B (1988) Radiovisiography (RVG): where reality surpasses radiological fiction. A hope that is becoming reality. *Journal of Dental Practice Administration* **5**, 138–40.
- Ellingsen MA, Harrington G, Hollender LG (1995) Radiovisiography versus conventional radiography for detection of small instruments in endodontic length determination. Part. 1. *In vitro* evaluation. *Journal of Endodontics* **21**, 326–31.
- Forsberg J (1987) A comparison of the paralleling and bisecting-angle radiographic techniques in endodontics. *International Endodontic Journal* **20**, 177–82.
- Furkart AJ, Dove SB, McDavid WD, Nummikoski P, Mattenson S (1992) Direct digital radiography for the detection of periodontal bone lesions. *Oral Surgery, Oral Medicine and Oral Pathology* **74**, 652–60.
- Griffiths BM, Brown JE, Hyatt AT, Linney AD (1992) Comparison of three imaging techniques for assessing endodontic working length. *International Endodontic Journal* **25**, 279–87.
- Hayakawa Y, Farman AG, Kelly MS, Kuroyanagi K (1998) Intraoral radiographic storage phosphor image mean pixel values and signal-to-noise ratio: effects of calibration. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **86**, 601–5.
- Hedrick RT, Brent Dove S, Peters DD, McDavid WD (1994) Radiographic determination of canal length: direct digital radiography versus conventional radiography. *Journal of Endodontics* **20**, 320–6.
- Horner K, Shearer AC, Walker A, Wilson NHF (1990) Radiovisiography: an initial evaluation. *British Dental Journal* **168**, 244–8.
- Kashima Y, Kanno M, Higashi T, Takano M (1985) Computed panoramic tomography with scanning laser-stimulated luminiscence. *Oral Surgery, Oral Medicine, Oral Pathology* **60**, 448–53.
- Kashima Y, Sakurai T, Matsuki T, Nakamura K, Aoki H, Ishii M (1994) Intraoral computed radiography using the Fuji computed radiography imaging plate: correlation between image quality and reading condition. *Oral Surgery, Oral Medicine, Oral Pathology* **78**, 239–46.
- Kullendorf B, Nilsson M, Rohlin M (1996) Diagnostic accuracy of direct digital dental radiography for the detection of

- periapical bone lesions. Overall comparison between conventional and direct digital radiography. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **82**, 344–50.
- Lavelle CL, Wu CJ (1995) Digital radiographic images will benefit endodontic services. *Endodontics and Dental Traumatology* **11**, 253–60.
- Leddy BJ, Miles DA, Newton CW, Brown CE (1994) Interpretation of endodontic file lengths using radiovisiography. *Journal of Endodontics* **20**, 542–5.
- Mouyen F, Benz C, Sonabend E, Lodter JP (1989) Presentation and physical evaluation of Radiovisiography. *Oral Surgery, Oral Medicine, Oral Pathology* **68**, 238–42.
- Olson AK, Goerig AC, Cavataio RE, Luciano J (1991) The ability of the radiograph to determine the location of the apical foramen. *International Endodontic Journal* **24**, 28–35.
- Ong EY, Pitt Ford TR (1995) Comparison of radiovisiography with radiographic film in root length determination. *International Endodontic Journal* **28**, 25–9.
- Powell-Cullingford AW, Pitt Ford TR (1993) The use of E-speed film for root canal length determination. *International Endodontic Journal* **26**, 268–72.
- Sanderink GCH, Huiskens R, Van Der Stelt PF, Welander US, Stheeman SE (1994) Image quality of direct digital intraoral X-ray sensors in assessing root canal length. The Radiovisiography, Visualix/Vixa, Sens-A-Ray, and Flash Dent systems compared with Ektaspeed films. *Oral Surgery, Oral Medicine, Oral Pathology* **78**, 125–32.
- Seki K, Okano T (1993) Exposure reduction in cephalography with a digital photostimulable phosphor imaging system. *Dentomaxillofacial Radiology* **22**, 127–30.
- Shearer AC, Horner K, Wilson NHF (1990) Radiovisiography for imaging root canals: an *in vitro* comparison with conventional radiography. *Quintessence International* **21**, 789–94.
- Shearer AC, Horner K, Wilson NHF (1991) Radiovisiography for length estimation in root canal treatment: an *in vitro* comparison with conventional radiography. *International Endodontic Journal* **24**, 233–9.
- Soh G, Loh FC, Chong YH (1993) Radiation dosage of a dental imaging system. *Quintessence International* **24**, 189–91.
- Sprawls P (1977) *The Physical Principles of Diagnostic Radiology*. University Park Press, pp. 196–200. Baltimore.
- Svanaes DB, Mystad A, Risnes S, Larheim TA, Grondahl HG (1996) Intraoral storage phosphor radiography for approximal caries detection and effect of image magnification. Comparison with conventional radiography. *Oral Surgery, Oral Medicine, Oral Pathology* **82**, 94–100.
- Van Der Stelt PF (1995) Digital radiology: deficiencies, failures and other adventures. *Dentomaxillofacial Radiology* **24**, 67–106.
- Velders XL, Sanderink GCH, Van Der Stelt PF (1996) Dose reduction of two digital sensor systems measuring file lengths. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **81**, 607–12.
- Versteeg CH, Sanderink GCH, Van Der Stelt PF (1997) Efficacy of digital intra-oral radiography in clinical dentistry. *Journal of Dentistry* **25**, 215–24.

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